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"Turn Left after the WC, and Use the Lift to Go to the 2nd Floor"—Generation of Landmark-Based Route Instructions for Indoor Navigation

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Abstract: People in unfamiliar environments often need navigation guidance to reach a destination. Research has found that compared to outdoors, people tend to lose orientation much more easily within complex buildings, such as university buildings and hospitals. This paper proposes a category-based method to generate landmark-based route instructions to support people's wayfinding activities in unfamiliar indoor environments. Compared to other methods relying on detailed instance-level data about the visual, semantic, and structural characteristics of individual spatial objects, the proposed method relies on commonly available data about categories of spatial objects, which exist in most indoor spatial databases. With this, instructions like "*Turn right after the second door, and use the elevator to go to the second floor*" can be generated for indoor navigation. A case study with a university campus shows that the method is feasible in generating landmark-based route instructions for indoor navigation. More importantly, compared to metric-based instructions (i.e., the benchmark for indoor navigation), the generated landmark-based instructions can help users to unambiguously identify the correct decision point where a change of direction is needed, as well as offer information for the users to confirm that they are on the right way to the destination.

Keywords: indoor navigation; route communication; landmarks; route instructions

1. Introduction

In daily life, people often encounter navigation problems when visiting a new place, e.g., "what's the way from the train station to the city hall". Outdoor navigation has been a research focus since the first location-based services. However, after arriving at a destination by using outdoor navigation systems, people often need to enter the buildings and start indoor navigation. Research has shown that compared to outdoors, people tend to lose orientation a lot easier within buildings, especially complex ones, such as hospitals, university buildings, big shopping malls, and airports [1,2]. Indoor navigation systems are designed to meet this need.

Different techniques can be used for communicating route/navigational information (directions) in indoor navigation systems, such as maps, verbal instructions (voice-based), augmented reality, and haptic [3]. Among them, verbal instructions have gained significant interests, as they do not demand people's visual attention [4]. Literature has shown that to improve navigation performance and provide good user experiences during navigation, landmarks should be included in route instructions, mainly due to their essential roles in human orientation and wayfinding [5,6].

Despite this importance, research on automatic creation of landmark-based route instructions is still on an early stage of development. Current approaches concerning this aspect are mainly limited to outdoors, and to the extraction of landmarks based on detailed data about the visual (e.g., facades and colors), semantic and structural characteristics of individual spatial objects (e.g., buildings) [7,8]. While for outdoor environments, this kind of information may be available for example in the form of geo-referenced images or digital cadastral maps, it is usually not available for indoor spatial objects, or difficult to obtain (Please note that for some new buildings, building information models (BIMs) or 3D models might exist, which contain information of indoor spatial objects. However, most of the existing buildings still lacks this kind of detailed indoor models).

An alternative approach named "landmark navigation model" is proposed in Duckham et al [9], which is category-based, and relies on commonly available data about categories of landmarks (i.e., Point of Interest POI dataset in their case), rather than detailed information about individual objects. Based on [9], Rouseel and Zipf [10] use OpenStreetMap data to generate landmark-based instructions for pedestrian navigation. These approaches are designed specifically for outdoor navigation. However, there exist significant structural differences between indoor and outdoor environments, i.e., fragmented, enclosed, clustered, high-architectural-variant and multi-level environments versus uncluttered, ordered and open spaces [11,12]. Therefore, several new challenges raise when applying category-based approaches for indoor navigation, mainly on the following aspects: *data sources* (e.g., the lack of indoor POI datasets), *landmark categories* (more landmark categories for indoors than solely POIs for outdoors), *landmark characteristics* (in terms of visual, semantic and structural aspects), *landmark selection over routing networks*, and *changes of floor levels*. More discussions can be found in Section 2.2.

This article aims to address these challenges, and develop a category-based method to generate landmark-based route instructions for indoor navigation. The proposed method is applied to the campus of the Vienna University of Economics and Business ("WU Campus") to evaluate its feasibility. The generated landmark-based route instructions are compared to metric-based instructions to illustrate the benefits brought by the method.

The rest of the article is organized as follows. Section 2 presents related work. In Section 3, we describe the proposed method. Section 4 reports on the evaluation, and Section 5 discusses the results. We draw conclusions and present future work in Section 6.

2. Related Work

2.1. Indoor Navigation Systems

Mobile navigation systems (e.g., car navigation and pedestrian navigation systems) are designed to facilitate users' navigation tasks in unfamiliar environments. According to [3], navigation systems usually consist of three modules: positioning (i.e., identification of users' current location), route planning (computation of a suitable route from an origin to a destination), and route communication (conveying turn information to guide users move along the planned route to reach the destination). Early research on this aspect often focused on outdoor navigation systems. Recently, research attentions have been drawn to indoor ones.

Current research on indoor navigation systems mainly focuses on indoor positioning (e.g., using WiFi, RFID, Ultra-wideband UWB, Bluetooth, Near-field communication NFC to estimate users' location) [13–17], and indoor routing (e.g., shortest routes, fastest routes, or routes meeting special needs) [18–20]. However, after a route from an origin to a destination is planned, route/navigational information (directions) should be effectively communicated to guide the user to reach the destination. Improper communication of navigational information could easily lead to the failure of the navigation task, or an unpleasant navigation experience. Despite this importance, research on indoor route communication is still on an early stage of development.

Different technologies/interfaces can be used for indoor route communication, such as route maps [21], 3D [22], audio (verbal instructions) [23], haptic [24], and AR [25]. Among them, verbal instructions have gained significant interests, as they do not demand people's visual attention [4].

This research focuses on verbal instructions, and aims to provide a method to generate landmark-based route instructions for indoor navigation.

2.2. Landmark and Landmark-Based Route Instructions

Sorrows and Hirtle [26] define landmarks as prominent and identifying features in an environment that can easily be recognized and memorized. The importance of landmarks for navigation has extensively been discussed in literature [5,6,27–29]. Landmark-based route instructions can reduce users' feeling of route confusion, as well as increase their confidence during navigation [29]. Undisputedly, landmarks are essential elements in navigation systems.

Raubal and Winter [8] propose a first approach to generate landmark-based route instructions for outdoor navigation, using a set of evaluation functions to assess the visual, semantic, and structural saliency of individual spatial objects (e.g., building). This approach is then extended by several other researchers [30–32]. In general, these methods rely on specific instance-level data about the visual (e.g., facades and colors), semantic and geometric characteristics of individual spatial objects and streetscapes. While for outdoors, this kind of instance-level information may be available for example in the form of geo-referenced images (e.g., street view images) or digital cadastral maps, it is usually not available for indoor spatial objects, or difficult to obtain for indoor spatial objects.

Duckham et al. [9] develop a rather different approach for outdoor navigation, which relies on commonly available data about categories of landmarks (i.e., POIs in their case), rather than detailed instance level data about the visual, semantic and structural characteristics of particular spatial objects. Their landmark navigation model for outdoor environments (OLNM) consists of two key components:

(1) A landmark weighting system to score POI categories according to how suitable they are as landmarks. To achieve this aim, they firstly identify a list of nine factors that contribute to "perceived" landmark suitability, i.e., visual (physical size, prominence, difference from surroundings, nighttime vs. daytime salience, proximity to road), semantic (ubiquity and familiarity to general public, length of description), and structural (spatial extents, permanence). For each factor of a particular POI category, they ask experts to give 5-point-likert ratings for the following two dimensions: (i) how suitable a typical instance of this category is as a landmark (from "Ideal" to "Never suitable"); (ii) how likely it is that a particular instance of this category is typical (from "All typical" to "Few"). After rating each POI category against each of the nine factors with respect to both dimensions, an overall suitability score for the POI category is derived and normalized. After this step, each POI category has a score about its (more precisely, its instances') suitability as landmarks.

(2) An algorithm for selecting landmarks and including them to generate landmark-based route instructions. To generate the instructions for a route from an origin to a destination, the algorithm firstly finds the set of POIs (landmark candidates) that lie along the route (on decision points or along route legs). Each of these POIs is then assigned the suitability score of its category, obtained from the above step. Their scores are then adjusted by considering the following aspects: side of road, existence of multiple landmarks on the same route leg. Finally, the POI with the highest score is selected for each decision point and each route leg longer than some length threshold, and included in the route instructions.

This category-based approach, as illustrated by Duckham et al. [9] for outdoor navigation, seems promising for indoor navigation, as it does not rely on instance-level data about the visual, semantic and structural characteristics of particular spatial objects, and these kinds of instance-level data are usually not available for indoor environments. However, due to the significant structural differences between indoor and outdoor spaces, several new challenges raise when applying category-based approaches for indoor navigation, mainly on the following aspects:

- Data sources: POI datasets as used in OLNM for outdoor navigation are usually not available for indoors; In contrast, indoor spatial databases often exist for indoor environments (e.g., university campus, hospitals), which contain a lot of information regarding different types of spatial objects within buildings, and should be classified and filtered before applying category-based approaches;
- Landmark categories: OLNM solely uses POIs as landmarks, while within buildings, in addition to indoor POIs (Similar to outdoor POIs, indoor POIs are defined as specific point locations that someone may find useful or interesting in the indoor environments. For example, in the study area WU Campus, some exemplary indoor POIs are lockers, vending machines, and computer terminals. Indoor POIs are usually less salient and less prominent than outdoor POIs), basic indoor spatial objects like rooms, stairs or doors can potentially serve as landmarks;
- Landmark characteristics: Indoor landmarks also dispose of different characteristics (in terms of visual, semantic and structural aspects) than outdoor landmarks, which affect the criteria for rating their landmark suitability;
- Landmark selection over routing networks: Routing networks in outdoor environments differ considerably from route paths in indoors, and therefore, selecting which landmarks to be included in the route instructions should be adapted to these specific characteristics of indoor environments; Additionally, indoor routes might lead directly through landmarks (e.g., rooms, lobby, doors) much more often;
- Multi-level travel: Compared to outdoor routes, indoor routes often involve change of floor levels. This aspect should be considered in generating landmark-based route instructions for indoor navigation.

2.3. Summary

In summary, as illustrated in the literature, landmarks play a role in human wayfinding, and they should be included in route instructions in navigation systems. Current approaches concerning the generation of landmark-based route instructions are limited to outdoor environments, and many of them rely on instance-level data about the visual, semantic and structural characteristics of particular spatial objects. The lack of these data for indoor environments hinders the application of instance-based approaches for indoor navigation. Category-based approaches, as illustrated by Duckham et al. [9] for outdoor navigation, are very promising for generating indoor route instructions. However, due to the significant structural differences between indoor and outdoor spaces (i.e., fragmented, enclosed, clustered and multi-level indoor environments versus uncluttered, ordered and open outdoor spaces), several key challenges exist when applying category-based approach for indoor navigation. This paper will address these main challenges, and develop a category-based approach to generate landmark-based route instructions for indoor navigation.

3. Indoor Landmark Navigation Model (ILNM)

3.1. Overview

Figure 1 gives an overview of the proposed method for generating landmark-based route instructions for indoor navigation. It consists of three steps: (1) Identification of categories of indoor spatial objects that may potentially serve as landmarks (Section 3.2); (2) Selection of landmarks for a specific route from a set of landmark candidates (Section 3.3); and (3) Integration of the selected landmarks to generate route instructions for the specific route (Section 3.4).

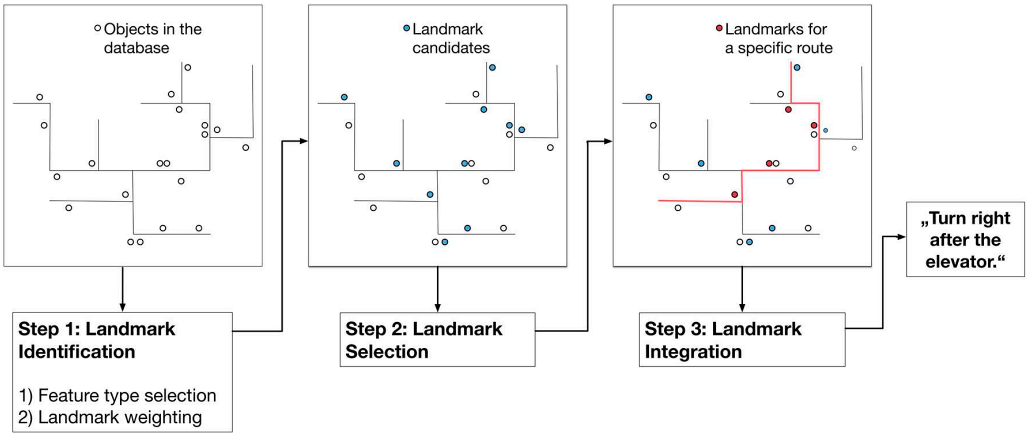

Figure 1. Overview of the proposed indoor landmark navigation model.

The first step is a pre-processing step, and involves some classification and expert ratings. It needs to be done once for each area of interest, e.g., a university campus, a hospital, and a shopping mall. However, after this pre-processing step has been done for a specific area of interest, the second and third steps can be then applied to automatically generate landmark-based route instructions for any set of origins and destinations.

This indoor landmark navigation model (ILNM) is designed to be used with indoor spatial databases. It does not depend on a specific data model. However, it is necessary that the following information can be derived from the spatial database of the area of interest: (1) individual indoor spatial features, which represent real-world indoor spatial objects (e.g., rooms, doors, and elevators) in the database, mainly their geometry (spatial extent) and the categories they belong to; (2) Routing network. We note that most existing indoor spatial databases would typically support deriving this basic information.

Please note that following OGC's definitions [33], ILNM differentiates between indoor spatial objects and indoor spatial features: While indoor spatial objects refer to real-world objects in the indoor environment, indoor spatial features are stored in indoor databases, and they are representations or abstractions of indoor objects. It is important to note that there might exist many indoor spatial objects in an indoor environment (e.g., rooms, vending machines, tables), however, not all of them are represented as spatial features in an indoor database (e.g., tables might not be represented in the database). In the following, we will mainly use the term "spatial feature", as we only focus on indoor spatial objects that are represented in indoor databases.

3.2. Identification of Landmark Categories

The first step of ILNM is to identify categories of indoor spatial features that may potentially serve as landmarks ("landmark candidates"), independent from a concrete route. This pre-processing step consists of two sub-steps: (1) Identifying categories of indoor spatial features that may be basically suitable as landmarks; (2) Scoring the suitability of each feature category as landmarks.

3.2.1. Identification of Indoor Feature Categories

Compared to outdoor navigation systems which can use existing POI categories for generating route instructions (see [9]), indoor navigation systems often need to rely on indoor spatial databases. Indoor databases usually contain a very large number of general indoor spatial feature categories. However, not all the spatial features may be suitable to serve as landmarks. Spatial feature categories with low salience for navigation should be removed. Based on existing research on landmarks and navigation, we only keep those categories that fulfill the following criteria:

- Recognizability. Spatial features (more precisely, their corresponding spatial objects) need to be recognizable on the route because of their shape, their label (e.g., room label like "toilet"), spatial extend, or other characteristics like door or interior (if visible from outside). Therefore, for a particular spatial feature category, if most of its instance features are generally not easily recognizable, this category would be removed.

- Availability in the area of interest. For a particular spatial feature category, if its instance features generally only occur on few, specific places (e.g., special room types), this category would not be selected. For example, for the POI category "self-service terminal", there only exist five of these terminals in the "WU Campus", which are located nearly next to each other. Therefore, the category "self-service terminal" might not be useful as a landmark category for the whole campus. Filtering out categories which only occur on few places was also due to practical reasons. Otherwise a lot of indoor feature categories would have to be rated which is very time-consuming (see Section 3.2.2 for more details).

Results of this step are a list of indoor feature *categories* that may be potentially suitable as landmarks.

3.2.2. Landmark Weighting

This sub-step aims to score the suitability of each selected indoor feature category as a landmark category. As discussed in the literature (e.g., [8]) a spatial feature is suitable as landmark when it differs from its surrounding with respect to its visual, semantic, and structural characteristics. In OLNM, Duckham et al. [9] develop a more detailed list of sub-characteristics (i.e., factors), tailored to determining the landmark suitability of POI categories for outdoor navigation. As indoor environments differ from outdoor environments both according to their landmark categories and characteristics, the original list in OLNM is revised to meet the requirement of indoor navigation.

Table 1 gives an overview of the proposed factors for scoring landmark suitability of spatial feature categories for indoor navigation. The new and modified criteria are marked with plus (+) and asterisks (*) accordingly. Note that we also remove the original factors "Nighttime vs. daytime salience" and "proximity to road" in OLNM, as indoor environments are usually well illuminated and proximity to road is not applicable.

Table 1. Detailed factors for scoring landmark suitability for spatial feature categories in ILNM (adapted from Duckham et al. [9]).

Characteristics	Factor	Explanation
Visual	Physical size *	Larger spatial features (more precisely, their corresponding spatial objects) are more easily seen, and therefore better candidate landmarks than smaller features. In indoor environments it has to be considered that often only a part of the feature is visible from the route (e.g., the door of a room). In these cases not the size of the feature itself is relevant but the size of its visible part.
	Prominence *	Spatial features that are visually prominent are better candidate landmarks than those with few or no distinguishing markings. Additionally, not only the prominence of the spatial feature itself but also of the feature label is relevant.
	Difference from surroundings	Spatial features that are typically different from their surroundings are preferable landmark candidates.
	Availability of an unique label+	Spatial features with a unique and visible label, which can be used as a reference in route instructions, are better landmark candidates than those without.
Semantic	Ubiquity and familiarity	Spatial features that are ubiquitous and familiar represent better candidate landmarks.
	Length of description	Spatial features that require shorter descriptions are more suitable landmarks than features that require longer or more complex descriptions.
Structural	Spatial extents *	Point-based spatial features are likely to be more suitable landmarks, as they are less ambiguous than features with spatial extents. In this context, rooms with a distinct door (e.g., offices, auditoriums) will be treated as point-based objects, as the door of the room represents the distinguishing marking in contrast to rooms without an explicit door (e.g., lounges, study areas), which will be rated as landmarks with spatial extents.
	Permanence	Spatial features that are expected to change or move less frequently make better candidate landmarks.

Similar to Duckham et al. [9], for each selected spatial feature category, we ask a group of experts (for example, in the case study in Section 4, 4 experts who are employees of the study area "WU Campus" were asked) to give 5-point-likert ratings on each of these factors, with respect to the following two dimensions: (i) how suitable a typical instance of this category is as a landmark (from "Ideal" to "Never suitable"); (ii) how likely it is that a particular instance of this category is typical (from "All typical" to "Few").

Table 2 shows some example ratings for the category of elevator of the study area "WU Campus" (Section 4). A typical elevator in "WU Campus" might be ranked as "Ideal" as a candidate landmark in terms of "physical size" (the doors of elevators are very large), "ubiquity and familiarity", "length of description", and "permanence" (elevators are usually not expected to move); "Highly suitable" in terms of "prominence" (the doors of elevators are usually quite prominent), "difference from surroundings" (elevator doors usually differ from other doors), and "spatial extents" (limited spatial extents, essentially point-like locations). However, elevators might be ranked as "Never suitable" in terms of the factor "availability of a unique label", as elevator doors at "WU Campus" are not labeled. While most of the above characteristics can be applied to all elevators at "WU Campus", the "high prominence" and "high difference from surroundings" are applicable only to most elevators, as few are in a less prominent position or have doors which are very similar to the wall.

Table 2. Example ratings of the category of elevator of the study area "WU Campus".

	Elevator	
	Suitability	**Typicality**
Physical size	Ideal	All
Prominence	Highly suitable	Most
Difference from surroundings	Highly suitable	Most
Availability of a unique label	Never suitable	All
Ubiquity and familiarity	Ideal	All
Length of description	Ideal	All
Spatial extents	Highly suitable	Most
Permanence	Ideal	All

These ratings for each spatial feature category are then combined to generate an overall suitability score, using the scoring system (Table 3) proposed by Duckham et al. [9]. For example, for the category of elevator, we can obtain its rating for "physical size" as 8, as its "physical size" is "Ideal" and "All", and its rating for "prominence" as 4, as its "prominence" is "Highly suitable" and "Most". Therefore, the overall score for the category of elevator is computed as: 8 + 4 + 4 + 0 + 8 + 8 + 4 + 8 = 44.

Table 3. Landmark scoring system based on spatial feature categories (Duckham et al. [9]).

Suitability	**Typicality**				
	All	**Most**	**Many**	**Some**	**Few**
Ideal	8	4	2	1	0
Highly suitable	4	4	2	1	0
Suitable	2	2	2	1	0
Somewhat suitable	1	1	1	1	0
Never suitable	0	0	0	0	0

After all the selected spatial feature categories have been rated and scored, a normalized weight can be then calculated for each category. The result of this process is a list of weighted spatial feature categories, which will be used in the landmark selection process for concrete routes in the next step.

3.3. Landmark Selection

After identifying landmark categories, their instance spatial features form a pool of candidate landmarks, to be selected when generating instructions for any indoor routes within the area of interest. In this section, we will define criteria and develop an algorithm for the landmark selection of a concrete route. As route paths in outdoor environments differ considerably from those in indoors, the OLNM selection algorithm had to be adapted to the specific characteristics of indoor environments:

- **Role in route instruction**. OLNM distinguishes between "landmarks at decision points (DPs)" and "in-leg landmarks". In ILNM, we introduce one more landmark type "crossed landmarks", which usually appear only indoors where a route may go directly through the landmarks, e.g., a particular room type (e.g., lounge and study area), a door and a hall. In contrast to "in-leg landmarks", which are selected only if the length of a route leg is exceeded a threshold, landmarks crossed by the route should be always selected due to their prominence on the route to create unambiguous instructions.
- **Location of landmark at DPs**. This aspect is not considered in OLNM. ILNM takes it into account as indoor environments are often more fragmented, enclosed, clustered, and with reduced visibility [12], and indoor landmarks are usually smaller and less salient than outdoor ones. Therefore, in indoor navigation, landmarks passed after re-orientation are often more difficult to be recognized before actually passing it. Therefore, landmarks located before the DP are ranked more highly than landmarks located after the DP.
- **Location of landmark on the route leg**. In OLNM "in-leg landmarks" are selected for route legs exceeding a threshold. The actual position of the landmark on the route leg is not considered. However, confirmation landmarks are usually much more valuable in the middle part of the route leg than other parts of the route leg [1]. Therefore, in ILNM in-leg landmarks that are located in the middle half of the route leg will be ranked higher.
- **Multiple landmarks on same route leg**. In case of multiple landmarks of the same category on a particular route leg, OLNM only selects its first instance. This approach does not seem to be applicable for indoor landmarks, as some landmarks (e.g., particular rooms) may occur regularly and in high numbers on the same route leg. Therefore, multiple landmarks on the same route leg will be considered using numerical chunking (e.g., "turn right after the second door"). To avoid cognitive overload, a count limit is set as five [34].

Based on the above consideration, we develop the following algorithm (Algorithm 1) to select landmarks for a specific indoor route. Please note that step (vi) remains unchanged as it is in the OLNM selection algorithm, and considers location of landmark with respect to the side of the path. This is based on the findings of Maass [35], which shows that wayfinders focus more on the side of the path that the next turn will be made toward [9]. Please also note that the geometry of spatial features are used in the algorithm to calculate whether they are visible on the route or at a decision point, as well as their locations related to decision points and route legs. The input "a list of individual spatial features" can be obtained from the previous step "Identification of Landmark Categories" (Section 3.2).

Algorithm 1: ILNM Landmark Selection

Input: a routing graph G, a list of individual spatial features L containing their spatial extents and landmark suitability weights, a start s and an end e, adjustment unit au, length threshold lt
Output: Selected landmarks for the route from s to e

(i) Generate a route from s to e based on routing graph G, using a shortest path algorithm (e.g., Dijkstra's).
(ii) Find the set of landmark candidates $L' \subseteq L$ that lie along the route (on DPs or along route legs).
(iii) Associate with each landmark instance $l \in L'$ the landmark weight of its category.
(iv) For any landmark $l \in L'$, increase its suitability weight with au if a unique visible label is available in the indoor environment.
(v) For any landmark $l \in L'$ at a DP, determine if the landmark is located before, exactly at or after the DP. Increase its suitability weight with au if it is located before the DP, and decrease it with au if the landmark is located after the DP.
(vi) For any landmark $l \in L'$ at a DP, increase its suitability weight with au if the landmark is located on the same side of the path as the upcoming instruction.
(vii) If multiple instances of the same landmark category occur on the route leg before the DP, set their weight to zero if their count n exceeds five, otherwise decrease their suitability weights with $(n-1) * au/4$, and store their number of occurrence.
(viii) For each DP, select the landmark that is incident with that DP and has the highest weight. If two or more landmarks have the same weight, select the landmark that is closest to the DP. For each selected landmark, determine its unique label, the position with reference to the DP, and the number of the instance.
(ix) For each route leg, select the landmarks that are crossed by the route. If multiple instances of the same landmark category occur on the same route leg, calculate their number.
(x) For each route leg that is longer than lt, determine the in-leg landmarks, and increase the suitability weight with au if the landmark is located in the middle half of the route leg.
(xi) If multiple instances of the same landmark category occur on the same route leg, set their weight to zero if their count n exceeds five, otherwise decrease their suitability weights with $(n-1) * au/4$.
(xii) For each route leg that is longer than lt, select the in-leg landmark with the highest landmark suitability weight. If two or more landmarks have the same weight, select the landmark that is nearest to the midpoint of the route leg.

The above algorithm has two specific parameters: adjustment unit au, length threshold lt. These parameters can be set through some empirical studies, or using some heuristics from literature. A detailed discussion on this aspect is provided in the case study in Section 4.3.1. After applying this algorithm, a set of landmarks can be selected for DPs and route legs of a concrete route.

3.4. Landmark Integration

In this step, the set of selected landmarks for DPs and route legs of a specific route will be integrated to generate landmark-based instructions for this route. Considering the characteristics of indoor routes, we make the following adaptations to OLNM:

- **Usage of path types instead of street names**. As street names are not available within buildings, indoor route instructions have to refer to the underlying type of the route leg to create route instructions like "Go along the path" or "Go along the corridor." For different indoor environments, different path types might exist. For example, in the study area "WU Campus", the following path types are available: ramp, elevator, stair, and general path (including corridor).
- **Consideration of routes through open spaces**. There are many open indoor spaces, which do not include clear paths to choose. For this case it has to be evaluated if a route leg goes through an open space (e.g., lounges, study areas), which is classified as landmarks. If yes, route instructions like "Pass through the study area" will be generated.
- **Handling of in-leg landmarks as point objects only and consideration of paths through landmarks**. OLNM distinguishes between point-based and polygon-based in-leg landmarks to

create instructions like "Continue pass ..." for point-like landmarks and "Continue along ..." for landmarks with spatial extents. ILNM does not have this differentiation, as indoor landmarks usually do not have that big spatial extent as outdoor landmarks (e.g., parks, rivers), and for polygon-based indoor landmarks like rooms the action "pass" will be more appropriate. However, for landmarks crossed by the route, irrespective from their spatial extent, ILNM uses the action "through".

- **Adaptation of route instructions for pedestrians and indoor scenarios**. OLNM creates route instructions in the form "⟨Perform action⟩ onto ⟨Street Name⟩ at ⟨Selected landmark⟩". To adapt these instructions for pedestrians and indoor use, the structure is changed to "Turn ⟨Direction⟩ ⟨Spatial preposition⟩ ⟨Number⟩ ⟨Selected landmark⟩" to create instructions like "Turn right after the second toilet".
- **Consideration of changes of floor levels**. As indoor routes often contain change of floor levels, this situation is considered and an instruction of the form "Use the ⟨Path type⟩ to go to the ⟨Destination floor number⟩ floor" is created.
- **Consideration of landmark location at DP**. The proposed ILNM determines if the DP landmark is passed before or after the DP. The algorithm incorporates this by differentiating between "before", "at" and "after" in the turn instructions.
- **DPs without selected landmarks**. In case of DPs without selected landmarks, OLNM uses street names to create turn instructions. However, in indoor environments instructions of this form may be ambiguous due to the lack of clear path names. Therefore, ILNM uses the default instruction "Turn ⟨Direction⟩ after ⟨Distance⟩" for DPs without selected landmarks.

Based on the above consideration, we develop the following algorithm (Algorithm 2) to generate landmark-based instructions for specific routes in indoor environments. Please note that the input "a list of selected landmarks" can be obtained from the previous step "Landmark Selection" (Section 3.3, Algorithm 1).

Algorithm 2: ILNM Landmark Integration

Input: a route from a start *s* and an end *e*, a list of selected landmarks, length threshold *lt*
Output: Landmark-based route instructions for the route from *s* to *e*

(i) i. (i) For each route leg for which crossed landmarks exist, create an instruction of the form "Go along the ⟨Path type⟩. You will pass through ⟨Number⟩ ⟨Selected crossed landmark(s)⟩".
(ii) For each route leg that is longer than *lt* and for which an in-leg landmark was selected create a route instruction:
  a. If a crossed landmark is selected, append to the previous instruction "and pass ⟨Selected in-leg landmark⟩".
  b. Otherwise generate a new instruction of the form "Go along the ⟨Path type⟩ and pass ⟨Selected in-leg landmark⟩".
(iii) For each route leg, for which neither a crossed landmark nor an in-leg landmark exists, create an instruction of the form "Go along the ⟨Path type⟩".
(iv) For each route leg, which involves a change of the floor level, create an instruction of the form "Use the ⟨Path type⟩ to go to the ⟨Destination floor number⟩ floor".
(v) For each DP with a selected landmark, generate an instruction of the form "Turn ⟨Direction⟩ ⟨Spatial preposition⟩ the ⟨Number⟩ ⟨Selected landmark⟩".
(vi) For each DP without a selected landmark generate an instruction of the form "Turn ⟨Direction⟩ after ⟨Distance⟩".
(vii) In case of the last leg of the route, create a new instruction:
  a. If the destination is located on the right or left side of the route, create an instruction of the form "Your destination ⟨Destination⟩ is located on the ⟨Spatial preposition⟩ side of the ⟨Path reference⟩".
  b. Otherwise create an instruction of the form "The ⟨Path type⟩ leads straight to your destination ⟨Destination⟩"

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4. Case Study: WU Campus

To test the feasibility of ILNM and to evaluate the quality of the resulting route instructions, we apply ILNM to the indoor spatial database of "WU Campus". This application is done by a simulation of a real implementation, i.e., by applying the rules and algorithms stepwise and manually, partly with the help of "ArcGIS 10.3". However, the logic behind these steps is designed to be performed automatically and therefore can be implemented into a real system.

The "WU GIS", available as an online map application, is developed to facilitate orientation on the campus. Users can search for rooms, departments, and other facilities. The base of the application is an indoor spatial database, which stores the geometrical data model of the campus. Most data are extracted from AutoCAD plans. Each object type is of a defined geometry type and is stored as a separate layer per floor. The most important spatial feature types are room, door, POI, network line (e.g., corridor, stair, and elevator). For all spatial features, different additional information is available.

4.1. Sample Routes

To evaluate the feasibility of the proposed ILNM for varying scenarios, three sample routes are selected from different buildings and different area types (Figure 2).

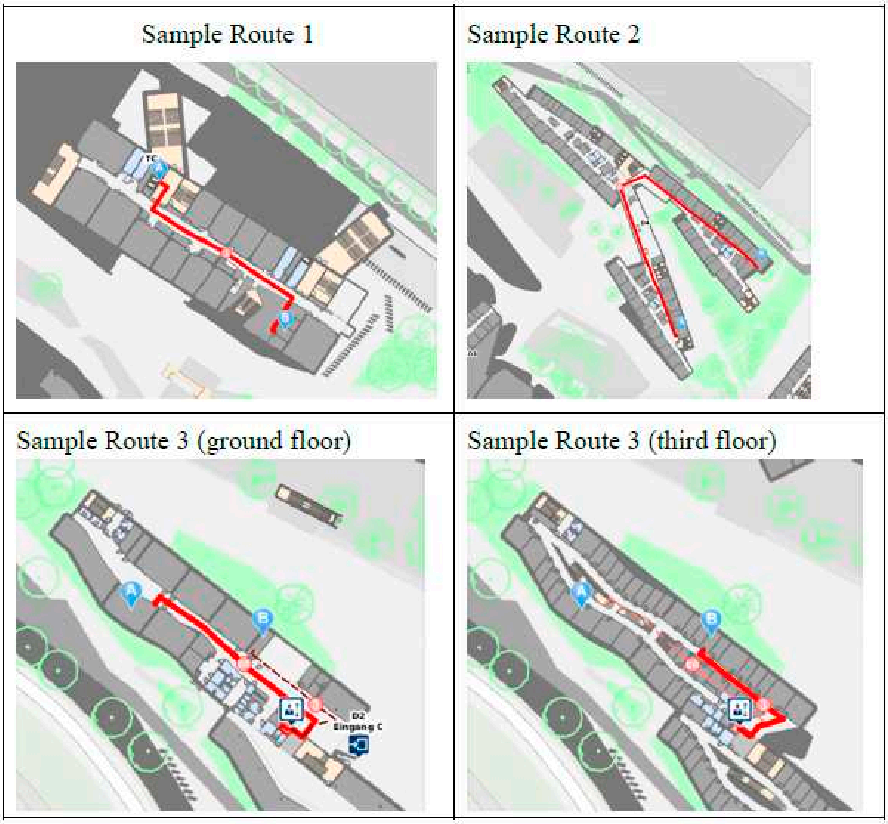

Figure 2. Three sample routes.

Sample route 1 is in a typical student area with different room categories and spatial objects like lockers or vending machines. It leads from one elevator of the third floor to the room TC.3.20. Sample route 2 is located in a department section with mainly offices and fewer outstanding features. On parts of the route, the corridor is divided into two sections by small rooms located in the middle. Sample route 3 leads from a seminar room on the ground floor to an office on the third floor. This route involves a change of floor levels. The ground floor represents a typical student area, while the third floor is a typical department section with mainly offices.

4.2. Identification of Landmark Categories for "WU Campus"

Selection of indoor object categories: To narrow down the landmark candidates, the ILNM preprocessing step (Section 3.2) is applied to all spatial features of the indoor spatial database of "WU Campus". All features are classified, generalized and only those feature categories whose instances are recognizable on the route and widespread available in the buildings are selected. In total, 21 spatial feature categories pass this selection, and they can be grouped into three main classes: *Basic spatial feature categories* (including stair, elevator, bridge, and door), *Room categories* (including auditorium, meeting room, seminar room, PC room, project room, lounge, study area, toilet, and uncategorized room), and *POI categories* (including locker, vending machine, computer terminal, front office, library self-checkout, library search terminal, scanner, and entrance/exit).

Landmark weighting: The expert rating on the landmark suitability of each of these 21 spatial feature categories is performed by four experts (two females and two males) who are WU employees and therefore know the indoor environments of the WU Campus very well. In an expert rating discussion, they agree on a ranking for each feature category according to the factors outlined in Table 1 (Table 2 gives an example for the elevator category).

After all spatial feature categories are rated, the overall suitability score for each feature category is determined using the scoring system (Table 3). The scores are then normalized. Table 4 shows the normalized weights of all the feature categories. Note that these weights are specific to "WU Campus". For other indoor environments, the above pre-processing step should be applied to rank the categories.

Table 4. Scoring of all landmark categories of "WU Campus".

	Overall Suitability Score	Weight Normalized with Respect to All 21 Categories Assessed
Stairs	52	1.00
Entrance/Exit	46	0.81
Locker	46	0.81
Elevator	44	0.74
Toilet	44	0.74
Vending machine	40	0.61
Auditorium	36	0.48
Computer terminal	36	0.48
Meeting room	32	0.35
Seminar room	32	0.35
Bridge	30	0.29
Door	30	0.29
PC room	29	0.26
Project room	29	0.26
Lounge	28	0.23
Front office	26	0.16
Library self-checkout	25	0.13
Scanner	25	0.13
Study area	23	0.06
Uncategorized room	22	0.03
Library search terminal	21	0.00

4.3. Sample Route 1

This section applies the proposed ILNM to generate landmark-based instructions for the sample route 1 step by step.

4.3.1. Landmark Selection

Based on the above spatial feature categories and their landmark suitability weights, we then apply the landmark selection algorithm (Selection 3.3) to select landmarks to be included for the instructions for the sample route 1. Some algorithm steps require specific parameters. For this case study several heuristics are used, for instance:

- **Suitability weight adjustment unit au**: For each increase or decrease of the suitability weight in the algorithm, the adjustment unit of 0.2 is used. This value represents a fifth of the maximum initial weight (i.e., 1) from the landmark weighting process and might provide a reasonable effect on the weight while keeping the influence of the initial weight sufficiently high.

- **Definition of visibility zone**: In order to define which features are visible from a route (step ii in Figure 1), a buffer zone around the route path is created with a distance of 4 m. The value of 4 m represents the assumed visible area and is a simplified method to determine which features are visible from the route. Please note that more comprehensive methods like viewshed analysis can be also applied [36].
- **Selection of visible landmarks**: Some spatial features require specific sub-steps to calculate their visibility from the route. For instance, for rooms it is necessary to determine if the door of the room is visible from the route, i.e., if the door is also within the buffer zone. For POIs, it is assumed that they are either visible if they are within the buffer zone and within the same room as the route path or within an adjacent room without door (e.g., a study area).
- **Length threshold for in-leg landmarks**: Particularly in indoor environments, where direction changes happen more frequently, a high density of in-leg landmarks is necessary to provide a confirmation that the user is on the right way. In this case study, we provide such confirmation for all route legs that take longer than around 30 s to walk. Assuming an average travel speed of 4 km/h for pedestrians in indoor environments [37], confirmation landmarks should be selected for all route legs longer than 33 m.

After applying the landmark selection algorithm and the above heuristics, we select the following landmarks for the sample route 1: Elevator, Door, Locker, Toilet "Men's WC TC.3.54", and Study area. Please refer to the Table A1 (Appendix A) for more details regarding the links between these landmarks and each route leg and decision point (DP).

4.3.2. Landmark Integration

As a last step within ILNM, the above selected landmarks are integrated to generate landmark-based instructions for the sample route 1, using the landmark integration algorithm proposed in Section 3.4. Figure 3 shows the sample route 1 and the selected landmarks along it. Table 5 shows the corresponding landmark-based instructions generated by ILNM.

Figure 3. Sample route 1 and the selected landmarks.

Table 5. Landmark-based instructions generated by the proposed ILNM for sample route 1.

Landmark-Based Instructions Generated by ILNM (Sample Route 1)	
(a)	Go along the path.
(b)	Turn right after the elevator.
(c)	Go along the path. You will pass through one door.
(d)	Turn left after the second door.
(e)	Go along the path and pass the lockers.
(f)	Turn right after the toilet "Men's WC TC.3.54".
(g)	Go along the path. You will pass through the study area.
(h)	Your destination is located on the left side of the path.

4.4. Sample Routes 2 and 3

Similarly, based on the spatial feature categories and their landmark suitability weights, we can then apply the landmark selection algorithm (Section 3.3) and the landmark integration algorithm (Section 3.4) to generate landmark-based instructions for the sample routes 2 (Figure 4 and Table 6) and 3 (Figure 5 and Table 7).

Figure 4. Sample route 2 and the selected landmarks.

Table 6. Landmark-based instructions generated by the proposed ILNM for sample route 2.

Landmark-Based Instructions Generated by ILNM (Sample Route 2)	
(a)	Go along the path.
(b)	Turn right after the room "D4.4.234".
(c)	Go along the path. You will pass through 2 doors and pass the elevator.
(d)	Turn right after the front office "Front Office Finance, Accounting and Statistics".
(e)	Go along the path. You will pass through 2 doors and pass the stairs.
(f)	The path leads straight to your destination "Room D4.4.144".

Figure 5. Sample route 3 (top: ground floor; bottom: third floor) and the selected landmarks.

Table 7. Landmark-based instructions generated by the proposed ILNM for sample route 3.

Landmark-Based Instructions Generated by ILNM (Sample Route 3)	
(a)	Go along the path.
(b)	Turn right after the seminar room "D2.0.038".
(c)	Go along the path. You will pass through 1 door and pass the toilet room "D2.0.012".
(d)	Turn right after the lounge "D2.0.005".
(e)	Go along the path.
(f)	Turn right at the elevator.
(g)	Go along the path.
(h)	Use the elevator to go to the third floor.
(i)	Go along the path.
(j)	Turn left after the second door.
(k)	Go along the path.
(l)	Your destination "Room D2.3.088" is located on the right side of the path.

5. Comparisons and Discussion

The above case study shows that ILNM is feasible in generating landmark-based instructions for routes within buildings. As demonstrated in the case study, ILNM relies on the categories of indoor spatial features and routing network, which can be easily derived from most existing indoor spatial databases. This proposed category-based approach is very different from instance-based approaches, which require detailed instance-level data about the visual, semantic, and structural characteristics (e.g., color and appearance) of individual spatial features. These kinds of detailed instance-level data are usually not available in existing indoor spatial databases.

In this section, we compare the landmark-based instructions generated by ILNM with metric-based instructions ("turn right after 50 m") to demonstrate the benefits brought by ILNM. After that, we discuss ILNM and the case study.

5.1. Comparison to Metric-Based Instructions

Metric-based instructions, which are often offered by car navigation systems for outdoor environments, can be considered as a benchmark. They mainly consist of street names, distances and turning directions. As street names are not applicable within buildings, we refer to the underlying type (e.g., path, elevator, stair, ramp) of the route leg when generating metric-based instructions (like "Go along the path"). Table 8 shows the comparison of landmark-based instructions by ILNM and metric-based instructions for the sample route 1. The comparisons of the other two sample routes can be found in the Table A2 (Appendix A).

Table 8. Comparison of landmark-based and metric-based route instructions (sample route 1).

Landmark-Based Instructions by ILNM	Metric-Based Instructions (Benchmark)
Go along the path.	Go along the path.
Turn right after the elevator.	Turn right after 2.7 m.
Go along the path. You will pass through one door.	Go along the path.
Turn left after the second door.	Turn left after 7.4 m.
Go along the path and pass the lockers.	Go along the path.
Turn right after the toilet: "Men's WC TC.3.54".	Turn right after 45.7 m.
Go along the path. You will pass through the Study area.	Go along the path.
Your destination is located on the left side of the path.	Your destination is located on the left side of the path.

The comparison shows that metric-based instructions mainly use distance information to indicate the point where a change of direction is needed. As humans are not good at judging the exact distance [5,27], metric-based instructions might lead to confusion and failure in identifying the correct decision point (DP). In particular, for DPs with preceding long route legs where multiple changes in direction are possible within a short distance, the metric-based instructions could easily lead to wrong navigation decisions. The generated landmark-based instructions use landmarks to indicate a DP, and therefore, can avoid this confusion.

For instance, the preceding route leg of the third DP of the sample route 1 is rather long with 45.7 m, and there are several possibilities for direction changes immediately before this DP (Figure 6). Therefore, the metric-based instruction "*Turn right after 45.7 m*" could easily lead to wrong navigation actions, whereas the landmark-based instruction "*Turn right after the second toilet: 'Men's WC TC.3.54'*" unambiguously indicates the correct DP.

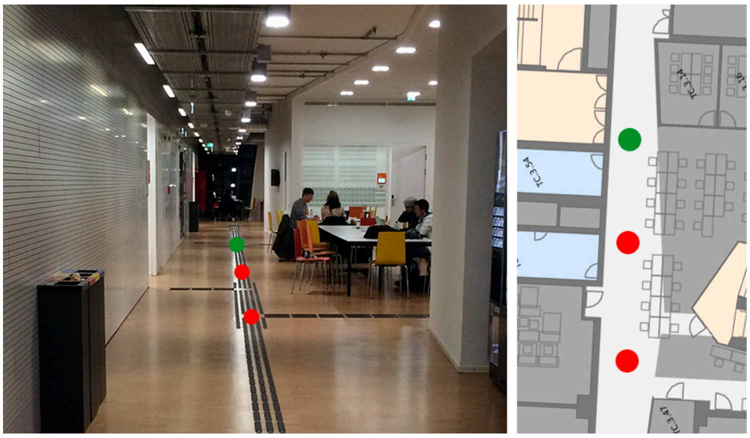

Figure 6. Open space and ambiguous possibilities for direction changes on sample route 1. The green dot indicates the DP where change of direction is needed, and the two red dots denote the points where people might potentially make turning mistakes.

In addition to DP landmarks, in-leg landmarks also play an important role in indoor navigation. The last route leg of the sample route 2 is rather long with 72.7 m (Figure 7) and the metric-based instruction "*Go along the path*" might create the feeling of uncertainty to the user. In contrast, the landmarks-based instruction "*You will pass through 2 doors and pass the stairs*" helps the user to confirm he/she is on the right way.

Figure 7. A long route leg on sample route 2.

The second route leg of route 3 is a long route leg with 40 m and there are multiple turning possibilities within a short distance (Figure 8). Compared to the metric-based instruction "*Go along the path. Turn right after 40 m*", the landmark-based instruction "*Go along the path. You will pass through 1 door and pass the toilet room 'D2.0.012'. Turn right after the lounge 'D2.0.005'*" helps the user to confirm he/she is on the right way, as well as easily identify the DP where he/she needs to turn.

Figure 8. A long route leg and multiple turning possibilities on sample route 3.

In summary, the above comparison shows that, compared to metric-based route instructions, the generated landmark-based instructions can better support users to unambiguously identify the correct DP where a change of direction is needed, as well as offer information for the users to confirm that they are on the right way. Both of these aspects will enhance users' navigation experiences, and help them to find their destinations much easier within indoor environments.

5.2. Discussion

As shown in the case study, the proposed ILNM can be used to generate landmark-based route instructions for indoor environments. Furthermore, the above comparison shows that compared to the benchmark in indoor navigation (i.e., metric-based instructions), the generated landmark-based instructions provide much clearer and unambiguous navigation guidance within indoor environments.

The proposed ILNM assumes the existence of an indoor spatial database for the area of interest. While it does not depend on a specific data model, it assumes that indoor spatial features (e.g., rooms, doors, and elevators), mainly their geometry and the categories they belong to, as well as a routing network can be derived from the database. We note that most existing indoor spatial databases would typically support deriving this basic information. Therefore, the proposed method can be easily applied to other types of indoor environments. However, the data quality (e.g., accuracy, consistency, and completeness) of the indoor spatial databases will have a significant impact of the quality of the resulting route instructions. Take data accuracy as an example. In contrast to outdoor environments, a deviation of only a few meters of indoor spatial features' footprints can lead to completely wrong route instructions. Therefore, high geometric accuracy is required, both for the routing network and indoor spatial features. In addition, the descriptive characteristics (e.g., category, label) of the individual spatial features need to be correctly defined for each feature, as this information is used in ILNM to select landmarks to be included in the route instructions.

In the case study, due to the absence of a 3D model of "WU Campus", we use a buffer of 4 m around a route to determine which features are visible from the route. This simple heuristic somehow makes sense and shows promising results in the case study. To provide more compelling results, one can also use various buffer sizes. For example, depending on the width of a route leg, a different buffer size is chosen. For buildings with an accurate 2.5 or 3D data model of the interior available, different visibility analysis tools can be used to accurately calculate the visibility of potential landmarks along a route, like what is done in [36] for outdoor navigation.

The current evaluation mainly compares the generated landmark-based route instructions to metric-based instructions. It can be improved by using wayfinding experiments with human participants. We would expect the generated landmark-based instructions would lead to much better wayfinding performances (e.g., higher success rate, lower decision errors, and more positive navigation experiences), as shown in the above comparison. In the meantime, we would also expect that compared to using metric-based route instructions, using the generated landmark-based instructions will enable people to better acquire spatial knowledge of the environment during navigation. For implementing the wayfinding experiment, a smartphone app will be created, for which we will also need to consider the timing to give the guidance instructions (e.g., at the beginning of a route leg or at the end). Meanwhile, indoor positioning (i.e., identifying the user's location in the building) should be also considered. We will investigate these aspects in a follow-up research.

6. Conclusions and Outlook

Many people have problems finding their way within buildings, especially complex ones, such as university buildings, hospitals and big shopping malls. This article proposed a category-based method (i.e., ILNM) to generate landmark-based route instructions to support people's wayfinding activities in unfamiliar indoor environments. Instead of relying on detailed instance-level data about the visual, semantic, and structural characteristics (e.g., color and appearance) of individual spatial features (which are usually not available in indoor spatial databases), the proposed ILNM relies on commonly available data about categories of spatial features, which can be easily derived from most existing indoor spatial databases.

The proposed ILNM, which consists of landmark identification, selection and integration, was applied to "WU campus". The case study with three sample routes showed that ILNM is feasible in generating landmark-based route instructions for indoor navigation. The evaluation results also indicate that compared to metric-based route instructions, the generated landmark-based instructions can better help a user to unambiguously identify the correct decision point where a change of direction is needed, as well as offer information for the user to confirm that he/she is on the right way. Both of these aspects can enhance users' navigation experiences, and help them to find their destinations much easier within indoor environments.

This work can be further improved by many different aspects, including:

- **3D data model**: With the rapid advances in mobile mapping technologies (e.g., LiDAR), more and more 3D building models are available for indoor environments. These 3D models can be used together with visibility analysis tools to accurately identify landmarks that are visible along the route, and further improve the quality of the resulting route instructions. 3D data models might also help to discover a new type of potential landmarks, e.g., landmark in the ceiling.
- **Mix outdoor/indoor navigation**: Daily wayfinding often involves mix outdoor/indoor environments. However, existing research on navigation systems deals with either indoor or outdoor navigation. An integration of both versions into one single system has hardly been considered. It is still unclear how a seamless navigation guidance between outdoor and indoor environments can be realized to avoid leaving the user disoriented.
- **Combination with route maps**: Compared to route instructions, route maps can offer an overview of the indoor environment. It would be interesting to see how route instructions and route maps can be combined to provide more effective navigation guidance in indoor environments.

- **Wayfinding experiments with human participants**: This work can be improved with a human subject experiment to further investigate the feasibility of ILNM, as well as the benefits of the resulting landmark-based instructions on the aspects of wayfinding performances and spatial knowledge acquisition.
- **Application to other indoor environments**: The proposed method in this work was primary developed for typical indoor environments, in particular public buildings like university campus, hospitals and office buildings. It would be interesting to apply the general workflow introduced in this work to other indoor environments, for example, complex transport hubs and shopping malls.
- **Indoor route planning**: Current indoor navigation systems often provide users with shortest routes. However, humans rarely move around using only these criteria. To better support indoor navigation, it would be interesting to explore methods to provide routes with other characteristics (e.g., simplicity, fewest-turns, floor-first, and main-corridor-first).

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Selected landmarks for the sample route 1 on "WU Campus". The numbers in brackets indicate the number of occurrence on the route leg to be used for numerical chunking. The spatial prepositions specify the position of the landmark with reference to the decision point (DP).

Route Leg	Landmark Type	Selected Landmark
Leg1	*Crossed landmark*	-
	In-Leg landmark	-
	DP landmark	Elevator (before, 1)
Leg 2	*Crossed landmark*	Door (1)
	In-Leg landmark	-
	DP landmark	Door (before, 2)
Leg 3	*Crossed landmark*	-
	In-Leg landmark	Locker (1)
	DP landmark	Toilet "Men's WC, TC.3.54" (before, 2)
Leg 4	*Crossed landmark*	Study area (1)
	In-Leg landmark	-
	DP landmark	-

Table A2. Landmark-based route instructions compared to metric-based instructions for the sample routes 2 and 3.

Landmark-Based Instructions by ILNM	Metric-Based Instructions (Benchmark)
Sample Route 2	
Go along the path.	Go along the path.
Turn right after the room "D4.4.234".	Turn right after 0.7 m.
Go along the path. You will pass through 2 doors and pass the elevator.	Go along the path.
Turn right after the front office "Front Office Finance, Accounting and Statistics".	Turn right after 66.7 m.
Go along the path. You will pass through 2 doors and pass the stairs.	Go along the path.
The path leads straight to your destination "Room D4.4.144".	The path leads straight to your destination "Room D4.4.144".

Table A2. *Cont.*

Landmark-Based Instructions by ILNM	Metric-Based Instructions (Benchmark)
Sample Route 3	
Go along the path.	Go along the path.
Turn right after the seminar room "D2.0.038".	Turn right after 1.6 m.
Go along the path. You will pass through 1 door and pass the toilet room"D2.0.012".	Go along the path.
Turn right after the lounge "D2.0.005".	Turn right after 40 m.
Go along the path.	Go along the path.
Turn right at the elevator.	Turn right after 4.2 m.
Go along the path.	Go along the path.
Use the elevator to go to the third floor.	Use the elevator to go to the third floor.
Go along the path.	Go along the path.
Turn left after the second door.	Turn left after 2.6 m.
Go along the path.	Go along the path.
Your destination "Room D2.3.088" is located on the right side of the path.	Your destination "Room D2.3.088" is located on the right side of the path.

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